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DIRECT-HEAT LUMBER DRY KILNS^{1/}

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During World War II the Forest Products Laboratory of the U. S. Forest Service, in Madison, Wisconsin, spent considerable time on the development of a kiln that could be used at small mills where gasoline or diesel engines or electric motors were used for power and no steam was available for heating the kiln. Sawdust was used for fuel in these early experimental kilns. The results obtained were encouraging; they indicated that such a kiln could be made to dry lumber satisfactorily. Commercial kiln companies have since made significant improvements in engineering and design of the heating systems, using both gas and oil for fuel. These fuels are easier to handle in a wide variety of commercial burners than sawdust or similar wood waste, and the difficulties experienced in the experimental sawdust-burning kilns have been overcome.

These kilns may be called direct-heat kilns, for the heat-generating mechanism is close-coupled with the drying chamber. The mechanism is an integral part of the kiln, constructed so the heat is either delivered directly into the kiln or transferred through a simple heat-exchanger or manifold.

The great number of oil- and gas-fired kilns that have been built during the past five years further indicates that direct-heat kilns can be made to dry lumber satisfactorily. They are now common in the central south, where gas is relatively cheap. There are also many kilns of this type in California, and some of them can now be found in most sections of the country.

This kiln design in which the heating system is close-coupled with the drying chamber has a number of advantages, but also some disadvantages. Perhaps the most important advantage is the fact that the kiln is an independent unit. No boiler is required. Operators of small sawmills and remanufacturing plants who have no steam plant find this a very real advantage.

^{1/} Paper given at the annual meeting of Western Lumber Dry Kiln Clubs, Corvallis, Oregon, May 11 and 12, 1951.

A second advantage is the economy of operating the heating system. The B.T.U.'s produced per gallon of oil or thousand cubic feet of gas are immediately available for heating the air within the drying chamber. There is little loss between the firebox and the lumber in the kiln. One commercial design, for example, has the heating system located within the kiln between two tracks of lumber.

A third advantage is the availability of moisture generated by combustion of the fuel for controlling the humidity within the kiln. This moisture supplements that given up by the lumber being dried, so that adding moisture from an outside source is seldom necessary during the drying cycle. For every gallon of high-grade fuel oil burned about 1 gallon of water is produced, and for every 1,000 cubic feet of natural gas burned, 11.5 gallons of water are produced. This latter figure is for the Rio Vista natural gas common to the central California area, but the figure should be fairly accurate for gas used in other areas as well.

This feature is most advantageous when drying certain species that require a fairly high humidity during the drying cycle, even well on toward the end of the run when little water is being given up by the lumber being dried. It may, on the other hand, be a distinct disadvantage when drying a species that requires a low humidity even at the start of the drying cycle, as in kiln drying sugar pine where low humidity is desirable to prevent or reduce the development of chemical brown stain. The additional venting necessary to get rid of the moisture from the gases of combustion increases the heat loss.

This type of equipment is also relatively easy to operate. Most manufacturers of these kilns are now furnishing pneumatic or electrical instruments for completely automatic control of the drying conditions. The better direct-heat kilns are able to maintain the drying conditions prescribed by the kiln schedules now in common use.

The low initial cost of these kilns is another advantage. Some direct-heat kilns have been built at a cost of 25¢ to 35¢ per board-foot capacity. These are well-constructed kilns of tile or cement block, with good heating and air-moving equipment.

Operating costs for these kilns are also low. Most of them are equipped with electric motors totaling $7\frac{1}{2}$ to 25 HP for operating both the heating system and the fan system. At current commercial rates in central California, electricity will cost from \$6.00 to \$15.00 per day. Fuel costs (both gas and oil) vary from 60¢ to about \$1.50 per thousand board feet dried. The direct operating costs of such an operation may therefore be as low as \$1.00 per thousand for some species that can be kiln dried on a fast schedule. A more realistic figure for the direct operating costs would be from \$3.00 to \$4.00 per thousand board feet. To this must be added the yarding, piling, and handling costs as well as all other costs incidental to such an operation.

Now let us look for a moment at some of the negative factors. The one that is no doubt uppermost in your minds is the fire hazard. There is a hazard. Some kilns of this type have been lost due to failure of the control equipment or break-down of the heating system. The temperature inside a gas-, wood-, or oil-fired furnace may exceed 2000° F., and if something should go wrong a serious fire may result. While experimenting with a kiln that burned sawdust for fuel we experienced two fires in one four-truck unit. The causes of the fires were apparent and steps were taken at once to correct these weaknesses, but the fact remains that the fire would probably not have occurred had the kiln been heated with steam. The firebox, with its high temperatures, is a constant danger point. Recognition of this fact should be helpful in reducing the likelihood of damage from uncontrolled fires. Some of the recently installed gas- and oil-burning kilns have been expertly engineered to reduce this fire hazard, and great progress has been made to reduce the fire risk in direct-heat kilns.

A second, and perhaps equally important disadvantage, is the difficulty encountered by most kiln manufacturers and operators in attaining the high final humidities required for stress relief. I have mentioned the case of controlling the humidity according to a predetermined drying schedule during the drying cycle. This can and is accomplished in most of the newer direct-heat kilns. There is still some difficulty, however, in producing the quantity of vapor necessary to raise the humidity within the kiln to the high level necessary for final equalizing and relief of drying stress. Water sprays located at the burner and throughout the kiln have been tried with varying degrees of success. I have been told by some of the leading kiln engineers that the greatest load on the heating system is at the start of a drying cycle when the kiln building and the lumber charge are cold. The demand for heat becomes less as the drying continues, even though the temperatures maintained within the kiln are increased. This initial peak load is not again reached, even during final conditioning. This would seem to indicate that a direct-heat kiln engineered to produce sufficient heat to satisfy the initial peak demand, has sufficient heat-generating capacity to vaporize water by the proper use of water spray nozzles at the combustion chamber or throughout the kiln.

This is not a particularly easy problem to solve, even in steam-heated kilns where the super-heat of the steam used for humidifying may cause the dry-bulb temperature to rise as the wet-bulb temperature rises, and high final humidities cannot be attained. This problem has lead to the use of steam-pressure reducers in the spray line and water injection pumps to mix water into the steam of the spray line. It is therefore not a problem peculiar to the direct-heat kilns. That this problem can be overcome was demonstrated at the Forest Products Laboratory, where a final wet-bulb depression of less than 5° was maintained with a dry-bulb temperature of 180° F. Our Forest Utilization Service representative from New Orleans recently reported that one manufacturer of direct-heat kilns in Arkansas has perfected a humidifying system for final conditioning at high temperatures and humidities.

Thus far I have spoken of direct-heat kilns in rather general terms. There are several types of these kilns now in use, and I'm sure you will be interested to know something about them.

The several types of kilns can be classified on the basis of differences in design and operation; as for instance, fan kilns and natural-draft kilns or compartment kilns and progressive kilns. For the purpose of this discussion I propose to divide them into two main types: (1) Those in which the hot gases from the combustion chamber are carried through the kiln in a system of pipes or ducts, then vented to the atmosphere; heat radiating from the surfaces of this heat-transfer system, or manifold warms the air within the kiln. (2) Those kilns in which the hot gases from the combustion chamber are dumped into the drying chamber.

Both of these types are similar in some respects. The burner and combustion chamber form an integral part of the kiln, and the temperature within the kiln is controlled by the rate of burning. This is accomplished by an automatic control of the burning rate at a "high" fire or a "low" fire, or by an automatic control of the fire at a burning rate that will maintain the set temperature. Automatic control of the draft damper on the sawdust burner very effectively maintained the temperatures within the experimental kilns in which sawdust was used for fuel.

The heat-manifold type includes both natural-draft and fan-type kilns. In the natural-draft kiln the heating tubes or manifold are located below the loads of lumber, in a pit similar in arrangement to the steam coils in the natural-draft kilns popular a few years ago. In one internal-fan kiln the firebox is located below track level outside one end of the kiln and the hot gases are conducted into the kiln through a large iron supply duct. The heat exchanger, located down through the center of the kiln, consists of many smaller iron pipes that extend up through the roof of the kiln from the supply duct, in the same location as a booster coil in a steam-heated kiln. The fan system consists of the typical long shaft with disc fans designed for cross-circulation of the air through the limber on both tracks.

A very simple design of kiln of the second type has a row of burners located down through the length of a double-track kiln between the two tracks of lumber. The location is similar to that of the heating system just mentioned, but the products of combustion are dumped directly into the kiln. Where fans are used, they are located above the burner through the longitudinal center of the kiln. They turn in a horizontal plane and the air circulation is up through the central plenum chamber past the heater and outward above the loads of lumber to both side walls and thus back through the loads. The direction of circulation can be reversed. The total air travel is the width of only one load of lumber, 7 to 10 feet, even in this double-track kiln.

One western kiln design is in some respects similar to our fruit dehydrators. Lumber is loaded cross-piled in a chamber through which air is driven lengthwise of the kiln. The air is returned through a bypass tunnel in which the burner is located. The two high speed fans that circulate the air can be reversed.

One of the more popular designs is a double-track kiln with the burner located outside at one end of the kiln between the tracks. Air from the kiln is forced both around and through the combustion chamber and then distributed along the length of the kiln from a large supply duct. Air from the kiln in large quantity at a normal kiln temperature of 120° to 180° or 190° F. mixes with and dilutes the air from the combustion chamber. The temperature of the air within the combustion chamber is thus reduced from $2000-2500^{\circ}$ F. to about $300-350^{\circ}$ F. as it enters the kiln. In this kiln the fans are also located in a horizontal plane through the longitudinal center of the kiln just above the tracks of lumber. The air travels from the central plenum chamber, over the loads toward the side walls, and then back through the lumber to the central plenum chambers, where it is reheated by additional hot air from the supply duct. The fans are reversed periodically, forcing the air down into the central plenum chamber, through the loads of lumber on each track, to the plenum chambers at the side walls, and thus back to the fans.

There are several other designs that are modifications of these general types. In fact, there is a multitude of designs of direct-heat kilns. This in general is a good thing, for it shows that many engineers are giving the problem considerable thought, and out of this should come a few best designs just as there are a few best designs of steam-heated kilns.

Our present-day kilns weren't created on a drawing board at a single sitting. They represent years of work, of modification and improvement. A brief review of the records shows how far we have progressed. According to Mr. Harry D. Tiemann, who recently retired from the Forest Products Laboratory, there are now over 370 U. S. Patents pertaining to the drying of lumber. The first was issued in 1862, to a Mr. Oliver for use of steam coils in drying lumber. In 1891 the internal fan was patented. It is interesting to know that a direct-heat kiln was patented in 1895. In the period 1910 to 1912 Mr. Tiemann developed the water-spray kiln with the first conception of humidity control, and in 1913 steam jets were introduced for the first time.

I have a record of eleven different direct-heat dry kilns now in use in California, and there are no doubt some I have not seen or heard of. This great interest in the direct-heat kilns indicates that this type of drying equipment is filling a very real need. The great variety of designs would also seem to indicate that some kilns may be less than the ultimate in design and engineering. It is my firm belief that further progress can be made in kiln design and operating techniques. This is an encouraging thought, for it holds out to us the promise of more well-seasoned lumber--an important factor in the fuller, more efficient use of our forest resources.

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